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Attentional Guidance by Salient Feature Singletons Depends on Intertrial Contingencies

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Evidence that salient feature singletons guide attention only when the target and the singleton frequently coincide has been taken to suggest that selection of singletons is under top-down control: Observers strategically use an attentional set sensitive to the singleton being a target. Changing the singleton–target (or singleton–distractor) coincidence also changes the opportunity for facilitative and disruptive intertrial effects to occur. The authors show that benefits and costs associated with certain singletons depend at least partly on the preceding trial type. Results are in line with dimensional weighting and perceptual priming accounts, which propose a (semi-) automatic transfer of dimensional activity from one trial to the next. Results also indicate that priming is set independently for each dimension.

One of the debates in the visual attention literature focuses on the extent to which salient visual stimuli capture attention automatically or are subject to top-down attentional control. Here, following Pashler (1988) and many others, we refer to a salient stimulus as a *feature singleton* or just *singleton*, as is usually defined by a local contrast on a perceptual dimension, such as color, orientation, motion, or abrupt transients (Hillstrom & Yantis, 1994; Kumada, 1999; Nothdurft, 1993; Theeuwes, 1992; Yantis & Jonides, 1984). Under the first, bottom-up, account, feature singletons capture attention regardless of the attentional state of the observer. These stimuli are often said to be processed "preattentively" because attention has no influence on them. Under the second, top-down, account, observers are able to influence whether they let their attention be guided by the singleton. According to this view, selection of singletons is subject to attentional control settings. As suits a proper debate, both views have gathered considerable evidence (e.g., Bacon & Egeth, 1994; Folk, Remington, & Johnston, 1992; Gibson & Kelsey, 1998; Pashler, 1988; Theeuwes, 1991, 1992; Todd & Kramer, 1994; Yantis & Egeth, 1999; Yantis & Jonides, 1984).

A primary piece of evidence usually interpreted in favor of the top-down view is the finding that attentional guidance by singletons depends on the coincidence of the target information the observer is looking for and the singleton property (e.g., a salient color; Folk et al., 1992; Folk, Remington, & Wright, 1994; Yantis & Egeth, 1999). For instance, Yantis and Egeth found that search for a relatively difficult to find orientation-defined target was aided when the target carried a unique color (turning it into a salient singleton) but only when the unique color and the target coincided frequently (e.g., on 80% of the trials). When the target and the unique color coincided infrequently (e.g., on 20% of the trials), search was inefficient even on those trials when the target carried the salient color. This finding suggests that observers used color when it was useful, but ignored it when it was not, arguing against a pure bottom-up account of attentional processing of singletons. Instead, attentional guidance appears to depend on which property (feature or dimension) forms part of the observer's attentional set (Folk et al., 1992).

However, note that changing the coincidence of the target and a singleton value (e.g., as a unique color) also changes the intertrial contingencies and, thus, the opportunity for particular intertrial effects to occur. For example, increasing the coincidence of the target and a unique color not only increases the chances of a uniquely colored target on the current trial but also increases the likelihood that the previous trial contained a similar uniquely colored target. It is known from several studies on visual search that previous trial type has an effect on performance on the current trial (Found & Müller, 1996; Hillstrom, 2000; Kumada, 2001; Maljkovic & Nakayama, 1994; McPeek, Maljkovic, & Nakayama, 1999; Müller, Heller, & Ziegler, 1995). For instance, Found and Müller presented observers with a mixture of two types of visual search displays that occurred with equal probability: One had an orientation-defined target, and one had a color-defined target. Although participants knew that both target types were equally likely and, thus, should have set their overall attentional strategy accordingly, Found and Müller found strong intertrial facilitation when a target on trial n was defined within the same dimension as the target on the previous trial ($n - 1$; e.g., a color target followed by another color target). Müller et al. (1995) proposed a

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dimension-weighting account in which one dimension on which salient signals are registered may receive more attentional weight at the expense of other dimensions (cf. Bundesen, 1998; Duncan & Humphreys, 1989). When the target matches the current weight settings, search is facilitated. However, if the target is defined on a different dimension, then weights need to be shifted to that dimension, leading to a reaction time (RT) cost. Note that the fact that these shifts in performance occur, despite the fact that both types of target are equally likely (and despite the fact that observers usually expect the target to change—the so-called gamblers' fallacy; Jarvik, 1951), implies that observers have little control over changes in attentional priorities between trials. Similar conclusions were reached by Maljkovic and Nakayama (1994), who attributed intertrial effects to bottom-up priming of the target dimension. Thus, where the effects of target–singleton coincidence have been taken to suggest top-down control of attentional guidance (Folk et al., 1992; Yantis & Egeth, 1999), they may actually reflect more or less automatic intertrial carryover effects.

In this article we look at the effect of different intertrial contingencies on attentional guidance by salient singletons. Figure 1 illustrates our visual search task, in which the target was always a larger bar among shorter and thinner distractor bars. On most trials, the target was gray and vertical. On 20% of the trials, however, the target had a unique (but irrelevant) color, as illustrated in Figure 1b. On another 20% of the trials, the target had a unique (but irrelevant) orientation, as illustrated in Figure 1c. We refer to these trials as *target singleton* trials. On a further proportion of trials, one of the standard distractors was replaced by a distractor of a unique color or orientation (20% each; see Figures 1d and 1e). We refer to these trials as *distractor singleton* trials. Finally, on the remaining 20% of the trials, neither the target nor any of the distractors had a unique color or orientation, and the target was solely defined by its size (Figure 1a). These latter trials served as the baseline against which the benefits and costs associated with target and distractor singletons could be compared.

On the basis of the studies on intertrial effects mentioned above, we predicted that RTs on trial n would depend on the target on trial $n - 1$. More specifically, we expected color-defined singleton targets to be more effective when the observer had just seen a color-defined target (and attentional weight had been shifted toward color) and orientation-defined targets to be more effective when the observer had just seen an orientation-defined target (and attentional weight had been shifted accordingly). Furthermore, we extended previous work on intertrial effects by looking not only at intertrial facilitation caused by singleton targets but also at intertrial costs caused by singleton distractors. For instance, color-defined targets may become less effective when preceded by a color-defined distractor (when presumably attentional weight is shifted away from color). Also, color-defined singleton distractors may become more disruptive after the presentation of a color-

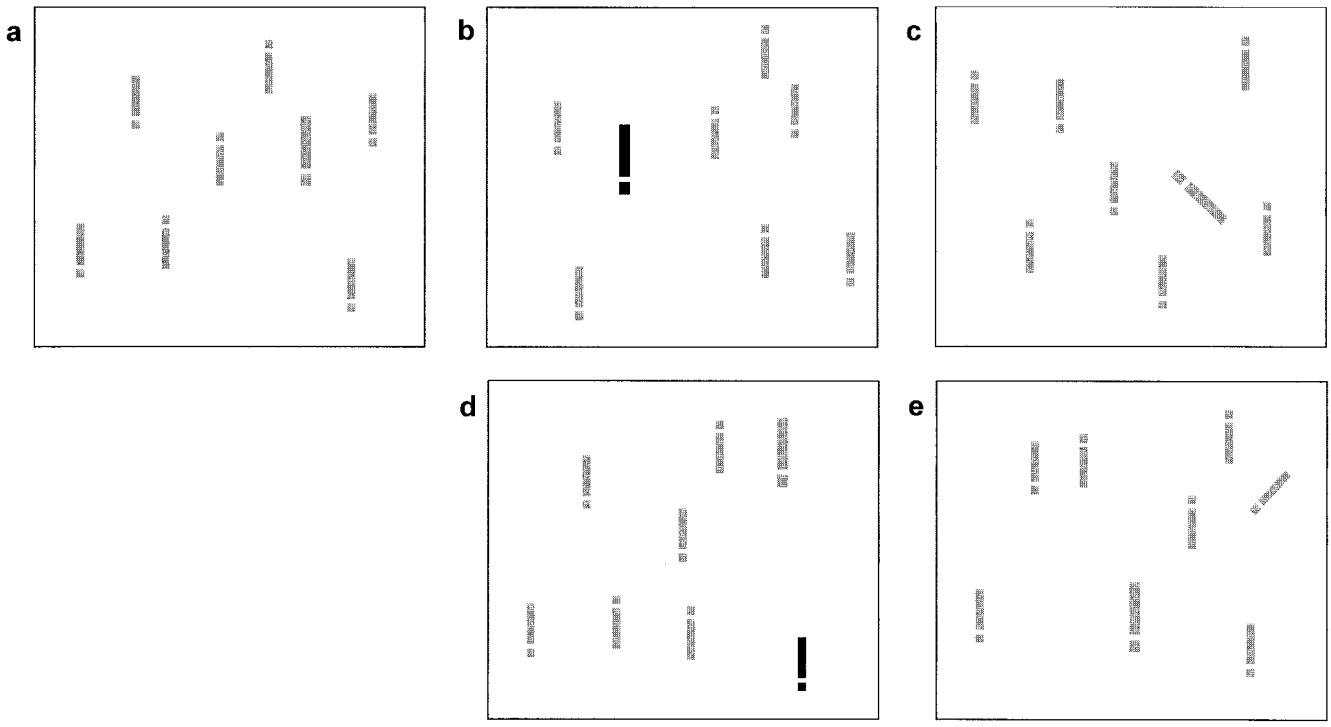

Figure 1. Stimulus display examples drawn from the experiment (not drawn to scale). The target was always the largest bar, and participants responded to the small notch on the bar (top or bottom). Panel a shows the baseline condition. Panel b shows a color-defined target singleton. Panel c shows an orientation-defined target singleton. Panel d shows a color-defined distractor singleton. Panel e shows an orientation-defined distractor singleton. The items were plotted in gray on a black background. Color singletons were either red or green.

defined target but less disruptive after the presentation of a color-defined distractor, with similar effects for orientation-defined singletons.

Method

Participants

Eighteen university students, ages 19–43 years, participated for money; 7 were men; 3 were left-handed. All had self-reported normal acuity and color vision.

Stimuli and Apparatus

Stimulus generation and response recording were conducted by a purpose-written Turbo Pascal 7.0 program running on a Pentium PC connected to an SVGA screen in 800 × 600 × 256 mode. The viewing distance was approximately 70 cm. A total of 16 search items were randomly plotted in the cells of a 5 × 5 virtual matrix subtending 7.5° × 7.5° of visual angle with some random jitter within the cells. The standard distractors were gray vertical bars (0.2° × 0.9°). The target was a larger bar of 0.3° × 1.2°. The target could be gray, red, or green and could be vertical, 45° left-tilted, or 45° right-tilted. Similarly, one of the distractors could be red or green and left- or right-tilted. Gray, red, and green were chosen to be isoluminant for Christian N. L. Olivers, as assessed by a flicker fusion test (Ives, 1912). Every bar had a small notch randomly placed at the top or the bottom.

Design and Procedure

Each trial started with a gray fixation cross, which stayed on throughout the trial. After 500 ms, a set of search items was presented. Participants responded to the notch on the target bar by pressing one of two mouse buttons, one for "top" and the other for "bottom." For this purpose the mouse was held sideways so that the arrangement of the buttons corresponded more or less to the orientation of the target bar. No mouse movements were required. After the response or after a time-out period of 3 s, the screen went blank for 500 ms. Feedback was provided by means of a low-pitch tone for incorrect trials (no sound for correct trials). Incorrect trials were those with an incorrect buttonpress or an RT outside the 200–3,000-ms range. The most important manipulation was the inclusion of different types of singleton, which are illustrated in Figure 1. In the baseline condition (20% of the trials), the target was a large gray vertical among gray vertical distractors. In the color target singleton condition (20%), the target was a large red or green vertical among gray vertical distractors. In the orientation target singleton condition (20%), the target was a large left- or right-tilted (45°) gray bar among gray vertical distractors. In the color distractor singleton condition (20%), the target was a large gray vertical among mostly gray vertical distractors. One of the distractors was either a red or a green vertical. Finally, in the orientation distractor singleton condition (20%), the target was a large gray vertical among mostly gray vertical distractors. One of the distractors was either a gray left-tilted or a gray right-tilted bar. In all conditions the largest bar was the target, regardless of color or orientation, and participants were explicitly instructed to search for the largest bar only while being told that all other variations in the displays were completely irrelevant to the task. There were four blocks of 200 trials each. Each block consisted of 100 randomly mixed pairs of trials, representing all 25 different 2-trial contingencies at least four times (i.e., baseline–baseline, baseline–color target singleton, baseline–orientation target singleton, etc.). Pairs were chosen so that if subsequent trials contained singletons of the same dimension (whether target or distractor), the feature values for those singletons would not be the same. Thus, for instance, a color target singleton–color distractor singleton pair would consist of a green target followed by a red distractor. We did this because we were more interested in dimensional effects than in possibly lower level perceptual priming of identical objects. However, because the last member of each pair formed the first member of the next pair, after randomization some consecutive trials could contain singletons of the same feature. This occured, on average, on 16% of the trials. Each block started with a randomly selected warm-up trial, which was excluded from any analyses. At the end of each block there was a short break in which the participants received feedback on their accuracy and RTs. In all, 100 trials of practice preceded the experiment.

Results

Correct RTs were first averaged per singleton type (baseline, color target, color distractor, orientation target, orientation distractor). Figure 2a shows the overall average RT benefits and costs associated with these singleton types, expressed as RT differences (dRTs) relative to the average baseline RT of 895 ms. Analyses of variance (ANOVAs) on dRTs revealed significant overall facilitation when the target was a color singleton, $F(1, 17) = 96.0$, $p < .001$, or an orientation singleton, $F(1, 17) = 66.4$, $p < .001$, but significant overall costs when one of the distractors was a color singleton, $F(1, 17) = 139.3$, $p < .001$, or an orientation singleton, $F(1, 17) = 26.5$, $p < .001$.

There was an influence of the preceding trial on the singleton effects. For this purpose we again calculated dRTs relative to the overall average baseline RT, but now for each combination of trials (i.e., baseline followed by baseline, baseline followed by color target, baseline followed by orientation target, etc.). The results are shown in Figures 2b–2d. Figure 2b shows that previous trial type had little effect on baseline trials ($p = .860$). Singleton target trials were analyzed with current trial type (color target, orientation target) and previous trial type (baseline, target of same dimension, target of different dimension, distractor of same dimension, distractor of different dimension) as factors. On average, color targets were responded to faster than orientation targets, an effect of current trial type, $F(1, 17) = 11.7$, $p < .01$. In addition, there were strong effects of the previous trial type, $F(4, 68) = 9.1$, $p < .001$. As can be seen from Figure 2c, singleton targets were responded to most quickly after trials containing singleton targets defined along the same dimension (i.e., color targets after color targets and orientation targets after orientation targets). In contrast, facilitation by singleton targets was reduced when the preceding trial contained a singleton distractor defined along the same dimension. This pattern was more pronounced for color targets than for orientation targets, leading to a significant Current Trial Type × Previous Trial Type interaction, $F(4, 68) = 3.0$, $p < .05$.

To assess facilitatory effects of previous singleton targets on current singleton targets, we compared singleton target trials following singleton target trials and singleton target trials following baseline trials. Note that singleton target trials were on average faster when preceded by a singleton target from the same dimension than after a baseline trial, $F(1, 17) = 10.1$, $p < .01$ (by 27 ms on average; 18 ms for orientation targets and 37 ms for color targets, although this difference was not significant, Current Trial Type × Previous Trial Type interaction, $p = .167$). In contrast, there was no facilitation when the singleton target trial was preceded by a singleton target defined along a different dimension, $F(1, 17) = 0.112$, $p = .743$ (−2 ms; 1 ms for color targets and −5

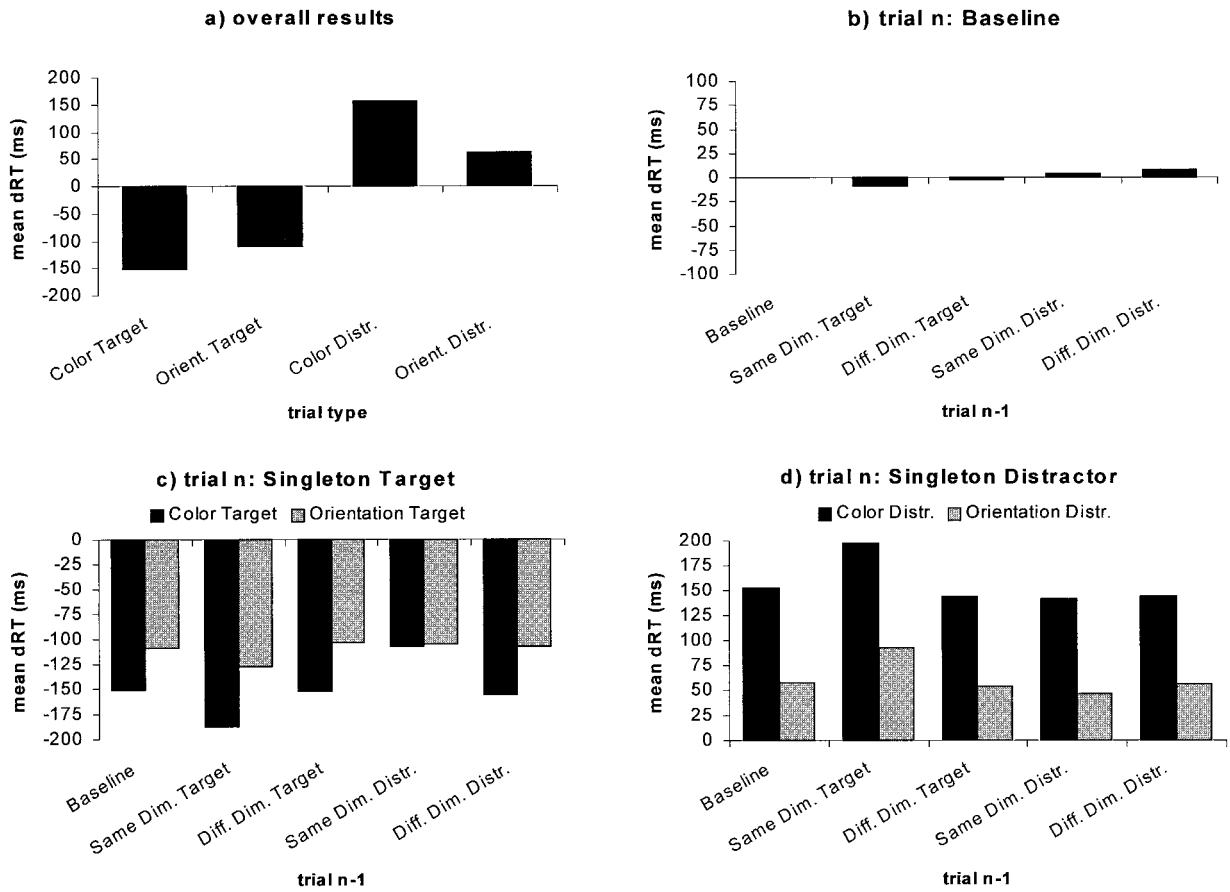

Figure 2. Experimental results. Response times (RTs) are plotted as differences (dRTs) relative to the average overall baseline RT, which was 895 ms. Panel a shows overall dRTs across trials. Panel b shows baseline dRTs as a function of the previous trial type, with same dimension arbitrarily assigned to color, and different dimension to orientation. Panel c shows singleton target dRTs as a function of the previous trial type, for color as well as orientation targets. Panel d shows singleton distractor dRTs as a function of the previous trial type, for color as well as orientation distractors. Orient. = orientation; Distr. = distractor; Dim. = dimension; Diff. = different.

ms for orientation targets; again, there was no interaction with current trial type, $p = .706$).

To assess inhibitory effects of previous singleton distractors on current singleton targets, we compared singleton target trials following singleton distractor trials and singleton target trials following baseline trials. Note that singleton target trials were on average 24 ms slower when preceded by a singleton distractor defined along the same dimension than when preceded by a baseline trial, $F(1, 17) = 4.7$, $p < .05$. There was a trend toward a Current Trial Type × Previous Trial Type interaction, $F(1, 17) = 3.4$, $p = .084$, as the reduction in RT was stronger for color targets preceded by color distractors (44 ms) than for orientation targets preceded by orientation distractors (4 ms). When the preceding distractor was from a different dimension, there was no difference relative to the baseline (−2 ms, $p = .872$; no interaction with current trial type, $p = .587$).

Looking at distractor singleton trials, we found color distractors overall to be more disruptive than orientation distractors, $F(1, 17) = 45.1$, $p < .001$. More important, however, there was again an effect of previous trial type, $F(4, 86) = 4.4$, $p < .01$. Figure 2d shows how singleton distractors were most disruptive after a trial containing a target of the same dimension (i.e., a color distractor after a color target, and an orientation distractor after an orientation target), and, to a lesser extent, less disruptive when after a distractor of the same dimension. There was no significant interaction with the current trial type (color, orientation; $p = .941$).

To assess the additional disruptive effects of preceding singleton targets on current singleton distractors, we compared singleton distractor trials following singleton target trials to singleton distractor trials following baseline trials. Note that singleton distractors became more disruptive when preceded by a singleton target trial of the same dimension, $F(1, 17) = 6.7$, $p < .05$ (by 40 ms on average; 46 ms for color distractors and 36 ms for orientation distractors; no interaction with current trial type, $p = .667$). There was no such additional disruption when a singleton distractor was preceded by a singleton target trial of a different dimension (−6 ms, $p = .619$; no interaction with current trial type, $p = .793$).

Singleton distractors were on average 11 ms less disruptive when preceded by singleton distractors along the same dimension than when preceded by a baseline trial (10 ms for color distractors and 11 ms for orientation distractors). Although in accordance with the overall pattern of results, this difference was not reliable ($p = .291$). When preceded by a distractor singleton of a different dimension, current distractor singletons were 5 ms less effective (*ns;* all interactions, $p > .80$).

Finally, following Maljkovic and Nakayama (1994), we were interested in the influence of trials occurring earlier than the immediately preceding one. To decrease noise and increase power, we calculated the mean total effect of previous color and orientation singletons on the current trial for color and orientation singletons as well as their average, as a function of the previous trial position (up to 10 trials preceding the current trial; see Maljkovic & Nakayama, 1994, for method).[1] It is clear from Figure 3 that, overall, preceding singletons had an influence on the current trial, as was confirmed in an ANOVA, testing the mean singleton effects against 0, $F(1, 17) = 35.2$, $p < .001$. These effects were stronger overall for color singletons than for orientation singletons, $F(1, 17) = 7.72$, $p = .013$, and there was no interaction with how far back the trial was presented ($F < 1$, $p = .725$). Furthermore, mean singleton effects became weaker the further back in time the trial was presented, $F(9, 153) = 2.45$, $p = .012$. Figure 3 shows that the decrease is quite gradual, with the effects of orientation singletons first being reduced to 0 when presented six trials back, and the effects of color singletons possibly extending even further back. One-tailed *t* tests indicated that the average singleton effects were significantly different from 0 for the first four positions, $t_{-1}(17) = 5.11$, $p < .001$; $t_{-2}(17) = 1.72$, $p = .052$; $t_{-3}(17) = 3.72$, $p = .001$; and $t_{-4}(17) = 2.64$, $p = .002$. There were also (close to) significant effects for Positions −5, −7, and −8, $t_{-5}(17) = 1.46$, $p = .081$; $t_{-7}(17) = 1.80$, $p = .045$; $t_{-8}(17) = 2.06$, $p = .028$. Note that under the number of post hoc comparisons made here (10), several of these effects may be classified as Type I errors. However, important aspects of the data make Type I errors less likely. First, the effects for Positions −1, −3, and −4 also held under Bonferroni corrections for multiple comparisons. Second, all effects were in the same direction. Third, and related to the second, the effects for certain positions matched those of neighboring positions. For instance, the effect at Position −8 could be a Type I error, but the fact that the same effect occurred at Position −7 makes it less likely a coincidence. Fourth, the effects were predicted on the basis of earlier findings by Maljkovic and Nakayama (1994). Nevertheless, to be on the safe side, we conclude that the singleton effects extend several trials back in time, with the strength of the effects gradually decreasing. This effect was reliably measurable for the first four positions but may extend further.

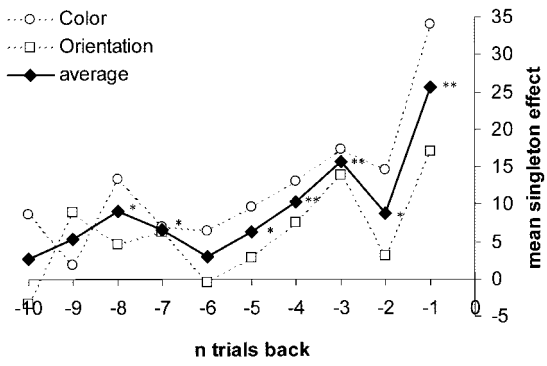

Figure 3. Mean total singleton effect of previous trials on current trials of the same dimension (color or orientation) and averaged across dimensions (average) as a function of previous trial position relative to the current trial. Single asterisks denote significant differences from 0 under one-tailed *t* tests on the averaged data ($\alpha = .05$; $\alpha = .08$ for Point −5); double asterisks denote significant differences from 0 under one-tailed *t* tests with Bonferroni correction ($\alpha = .005$).

Errors

Table 1 shows the error rates as difference scores from the overall baseline rate (which was 3.5%). On average (see the bottom row of Table 1), the errors followed the pattern of RTs closely ($r = .87$), with singleton target conditions leading to fewer and singleton distractor conditions leading to more errors than the baseline condition. The facilitation was significant for color targets, $F(1, 17) = 6.43$, $p < .05$, but not for orientation targets ($p = .43$). The disruption was significant for both color and orientation distractors, $F(1, 17) = 32.0$, $p < .001$, and $F(1, 17) = 25.5$, $p < .001$, respectively. Color targets led to fewer overall errors than orientation targets, $F(1, 17) = 4.72$, $p < .05$, with no clear effects of previous trial type (main effect and interaction ps $> .11$). Color distractors, on the other hand, were not reliably more disruptive than orientation distractors in terms of errors ($p = .167$), nor was there any main effect of or interaction with the previous trial type (ps $> .296$). We conclude that the pattern of RTs was not contaminated by speed–accuracy trade-offs.

Discussion

Figure 2 clearly shows that benefits and costs depended to a large extent on the preceding trial. Observers were particularly fast in responding to a singleton target when they had just seen a target of the same type on the previous trial. If they had just had a singleton distractor or baseline trial, they were slower. Conversely, observers suffered more from singleton distractor trials when they had just seen a singleton target trial of the same dimension, relative to when they had just seen a baseline trial or another distractor trial of the same dimension. Furthermore, Figure 3 suggests that this influence was not limited to only the immediately preceding trials but to singletons occurring several trials back. These results suggest that the attentional state of observers was continuously tuned, on a trial-by-trial basis, and that this tuning was affected by the processing of previous targets as well as distractors.

[1] The mean total singleton effect (MTSE) was calculated separately for color and orientation singletons, as follows: $\text{MTSE} = (\text{dRT}_{\text{distractor}\rightarrow\text{target}} - \text{dRT}_{\text{baseline}\rightarrow\text{target}}) + (\text{dRT}_{\text{target}\rightarrow\text{distractor}} - \text{dRT}_{\text{baseline}\rightarrow\text{distractor}}) - (\text{dRT}_{\text{distractor}\rightarrow\text{distractor}} - \text{dRT}_{\text{baseline}\rightarrow\text{distractor}}) - (\text{dRT}_{\text{target}\rightarrow\text{target}} - \text{dRT}_{\text{baseline}\rightarrow\text{target}})/4$, with $\text{dRT}_{a\rightarrow b}$ = the RT difference to the baseline for trial type *b* when preceded by trial type *a*. The average shown in Figure 3 is the average MTSE across color and orientation singletons.

Table 1
Error Percentages Expressed in Difference Scores Relative to Overall Baseline Error Rate

	Current trial (*n*)				
Previous trial (*n* = 1)	Baseline	Color target	Color distractor	Orientation target	Orientation distractor
Baseline	−0.3	−0.8	1.9	−0.4	1.0
Color target	0.0	−2.0	2.1	−0.8	2.9
Color distractor	0.4	−0.9	3.3	−0.2	2.8
Orientation target	0.4	−2.1	2.8	0.7	2.7
Orientation distractor	−0.5	−1.4	4.3	−1.8	2.0
Average	0.0	−1.4	2.9	−0.5	2.3

Note. Overall baseline error rate (averaged across all baseline trials) is 3.5%.

The overall effects, as well as the intertrial effects, were more pronounced for color targets than for orientation targets. This finding corresponds to previous observations (Found & Müller, 1996; Hillstrom, 2000; Müller et al., 1995) and probably reflects the difference in salience between color and orientation here. Given this, the color targets were likely to lead to, on the one hand, stronger priming or attentional weight shifting and, on the other hand, the necessity for stronger inhibition, relative to orientation targets.

Automatic or Top-Down Controlled?

An important question is whether this trial-by-trial modulation is automatic or subject to top-down attentional control. On the first, automatic, account, observers cannot avoid being influenced by the information presented on the previous trial. This is not necessarily to say that search on the trial itself is not influenced by top-down control. For instance, on trial *n*, participants may actively attend to a color target or attempt to inhibit a color distractor. However, subsequently, participants may have little or no control over what is transferred to the next trial. Thus, the next color singleton may be either primed or inhibited even though participants know it is equally likely to be a target or a distractor. This way, automatic processing is contingent upon previous top-down control settings—something Bargh (1992) referred to as "conditional automaticity."

On the second, top-down, account, observers may deliberately alter their attentional control settings for the current trial, on the basis of what worked best on the previous trial. For instance, when confronted with a color target on trial $n = 1$, participants may decide to search again for a color target on trial *n* if there is a reasonable chance of such a target occurring. This then leads to faster responses when a color target is indeed present but to slower responses when the color singleton turns out to be a distractor. Although we cannot completely exclude the top-down account on the basis of our data, we believe the (contingent) automatic account is more likely for the following reasons.

First, Found and Müller (1996) attributed similar intertrial effects to an attentional dimension-weighting account, according to which attention is guided by the weighted sum of dimension-specific saliency signals. The target dimension (Found and Müller, 1996, used color and orientation), when known, may receive extra weight, leading to faster computation of the most salient location and, consequently, faster detection. When the target dimension is not known (color and orientation trials mixed), then dimensional weights need to be shifted on a trial-by-trial basis instead, leading to relative costs. This "online" weight shifting itself may be a top-down process, but note that Found and Müller suggested that the weight shift automatically persists into the next trial, as they found intertrial effects even though the identity of the next target was known with only a 50% chance. Recent experiments by Reimann, Müller, and Krummenacher (in press) suggest that some, but not all, of this cross-trial persistence may be overcome by top-down processes (those induced by cuing; see also Los, 1996, 1999). In our experiments, we found intertrial effects with color and orientation targets that occurred only on, respectively, 20% of the trials. Moreover on another respective 20%, the color or orientation singleton was actually a distractor. There would thus be even less incentive to deliberately shift weights toward one dimension or another.

Second, Maljkovic and Nakayama (1994) also found that RTs were relatively facilitated when the target feature was repeated (note that where Maljkovic and Nakayama repeated features, we, as well as Müller and colleagues, typically repeated dimensions). They attributed the intertrial facilitation to bottom-up priming of the target feature and not to top-down attentional control on the basis of several findings. First, they demonstrated that the priming effect was not influenced by the expectancies of the observers, nor was it subject to conscious control. Second, as we did, they found priming effects for targets presented up to several (in their case, eight) trials back. It is highly unlikely that participants consciously remembered up to eight previous trials and adjusted their attentional set accordingly in a top-down fashion. Indeed, Maljkovic and Nakayama (2000) showed that participants have no explicit memory for any but the immediately preceding trial (see also Müller, Krummenacher, & Heller, 2002, for similar conclusions). Moreover, in our experiment almost all participants reported that they had attempted to ignore the color and orientation information. Most said that they only partially succeeded, whereas others reported that they were not at all affected by the singletons (their data showed otherwise). Together, these findings suggest that observers have little control over the activation carried from previous trials.

Nevertheless, it is important to point out that our data do not rule out the influence of overall top-down attentional control settings. For this we would have to look at any residual costs and benefits not contingent on the previous trial. Figure 2 indicates that there are indeed residual costs and benefits stemming from other sources than the immediately preceding trial. For instance, target singletons remained facilitating overall even when preceded by a distractor singleton. These effects may partly originate from an overall attentional set. However, we also know from Figure 3 that, at least partly, they originate from previous trials beyond the immediately preceding one. Thus, our data do not speak clearly for or against an overall attentional set. In any case, we conclude that merely altering the proportions of trial types within a block is not the best way of inducing certain top-down attentional control settings, as altering proportions also leads to altering the different intertrial contingencies and their related priming effects.

Perceptual Priming, Dimension Weighting, or Response Facilitation?

Are intertrial effects due to priming, dimension weighting, both, or neither? Maljkovic and Nakayama (1994; see also Hillstrom, 2000) found intertrial facilitation for repetitions on the feature level (e.g., red followed by red relative vs. red followed by green) and attributed this to priming (e.g., prior activation). In contrast, Found and Müller (1996) reported intertrial facilitation for repetitions of the dimension defining the target (e.g., color followed by color vs. color followed by orientation) and attributed this to changes in the attentional weights attached to the target dimension. In our experiment too, repetitions were mainly based on the dimension level rather than on the feature level (with only a minority of repetitions, 16%, being feature repetitions; see the Method section; the pattern of results remained the same when these feature repetitions were excluded from analyses). Nevertheless, as indicated above, our data show some similarities to Maljkovic and Nakayama's data, including cross-trial effects stemming from several trials back, and it would be appealing to suggest that similar or identical mechanisms underlie both data sets. Also encouraging in this respect are the results of Found and Müller's Experiment 2, in which they demonstrated effects for repeated features on top of facilitation effects for repeated dimensions. Thus, the two accounts may be unified by suggesting that when observers have found a certain salient target, attentional weights are broadly shifted toward the dimension in which the salient feature was defined and are more narrowly shifted toward the actual feature value within that dimension.[2]

Of further interest, our data suggest that the dimensional weight shifting may occur independently for each dimension. Turning attention either toward or away from color did not appear to affect selection of orientation targets, or vice versa. This stands in contrast to results found by Müller and colleagues (Krummenacher, Müller, & Heller, 2001; Müller et al., 1995), suggesting that an attentional shift toward color draws attention away from orientation, and vice versa. Part of this discrepancy may be explained by the fact that Müller and colleagues' participants always had to shift between color and orientation, whereas observers in our experiment could revert back to size as the crucial target property after color or orientation had failed on the previous trial. Shifting back to size would thus act as a buffer between color and orientation. The fact that color and orientation trials had, nonetheless, little influence on baseline trials (with solely size-defined targets; see Figure 2b) may be explained by the fact that size was present on every trial (as it was the target-defining property) and may have been assigned attentional weights or priming activation accordingly.

Above (and throughout this article) are outlined what we would term *perceptual* accounts of intertrial effects, in which shifts in the perceptual or attentional weights applied to particular stimulus dimensions or features are thought to determine the ease with which a target is selected. An alternative view, however, is that the prior occurrence of a target defined on one dimension primes a response to that dimension within a separate system concerned with response rather than stimulus selection (Cohen & Magen, 1999; Cohen & Shoup, 1997). In accordance with this idea, Cohen and Magen found that interdimensional costs completely disappeared (or even turned into benefits) when they changed the response requirements from a "target-present/absent" decision (as in most of Müller and colleagues' experiments; e.g., Found & Müller, 1996) to a "target is color-orientation-defined" decision. More support for a response-based account comes from recent work by Kumada (2001), and Theeuwes and Reimann (2002), who found dimensional effects for detection search tasks (present/absent) but not compound search tasks (in which the observer has to decide on an irrelevant feature of the target, and thus the response is uncoupled from the target-defining feature). However, here we found clear evidence for intertrial carryover effects in search for a compound target. This has also been found by Maljkovic and Nakayama (1994), Hillstrom (2000), Krummenacher, Müller, and Heller (in press), and Theeuwes and Reimann (2002), who found compound search to be insensitive to dimensional cuing but still sensitive to intertrial effects. Moreover, we found intertrial effects stemming from distractors, to which no response was required. We therefore believe the bulk of the evidence points toward a perceptual account.

[2] We prefer the term *weight shifting* over the term *priming* because priming is associated with facilitation generated on a lower perceptual level rather than an attentional level. The present experiment shows that when singleton distractors capture attention, subsequent singleton targets and distractors of the same dimension lose some of their effects (i.e., they are suppressed). A straightforward priming account would predict that their effect would be increased, as their processing should have been facilitated because of the attention they received previously. Instead, the moderating effect of singleton distractors on subsequent trials suggests a change in attention, involving the shifting away of attentional weight from the distracting dimension or feature (see also Kumada & Humphreys, 2002, for evidence of singleton distractor inhibition). Nevertheless, such inhibitory carryover effects from one trial to the next have previously been referred to as *negative priming* (e.g., Tipper, 1985), thus rehabilitating the term *priming*. Indeed, our results may represent a special instance of negative priming applied to visual search. This appears to be an issue of terminology.

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